which conjugates, and which is furnished with only two cilia. The only distinction between the macro- and microzoospores seems to be that the former have four cilia, the latter only two. When the microzoospores fail to conjugate they may develop non-sexually just like the macrozoospores. This is a fact of the highest importance. In this plant, belonging to the lowest group in which sexual reproduction occurs, the sexual and non-sexual zoospores are hardly to be distinguished, and if by any chance union of the sexual zoospores does not take place, the zoospore behaves like a macrozoospore and develops non-sexually.

After remaining in a state of rest, sometimes for nearly twelve months, the contents of the zygospore break up into zoospores, from which arise the filamentous stage of Ulothrix.

In Ulothrix the conjugating cells are generally morphologically and physiologically identical, but sometimes larger zoospores conjugate with smaller, a difference in sex being here indicated. In other cases the microzoospores which have not conjugated germinate and give rise to individuals capable of reproducing. The study of the formation and subsequent development of the zygospore shows that the product of conjugation is to be considered as a new sexually-produced generation. It is a unicellular plantlet, with a root-like process and a slowly-growing plant-body which performs the function of assimilation. It in fact represents the embryo and the sporophore of the Pteridophytes. The root-end of the plantlet is formed by the union of the germinal spots of the conjugating microzoospores, while the assimilating plant-body represents the united chlorophyll-bearing parts of the zoospore.

The Ulothrix is thus one of the Zygosporeæ, and is probably related to Hydrodictyon, but it shows certain affinities to Sphæroplea, the lowest of the Oosporeæ.

As this part concludes the tenth volume of this serial, a most useful table of contents and special index of names of plants and details treated of in all the papers in the ten volumes has been added by Herr Zopf. This enables the student at once to refer to any given plant, or even to the part of it described in the various papers.

W. R. McNab

THE ROYAL NAVAL COLLEGE, GREENWICH

On February 1, 1873, the Royal Naval College was opened at Greenwich, "for the purpose of providing for the education of naval officers of all ranks above that of midshipman in all branches of theoretical and scientific study bearing upon their profession." The first annual report on the Royal Naval College thus established has been recently presented to both Houses of Parliament.

When the College was established it was determined by the Admiralty to bring together in it all the necessary means both for the higher education of naval officers and also of others connected with the navy. During the session which terminated last year four captains, four commanders, ninety-three lieutenants, and eight navigating-lieutenants joined the college as students, but of these only one captain, thirty-three lieutenants, and three navigating-lieutenants went through the whole nine months' course, although one captain, two commanders, fifty lieutenants, and three navigating-lieutenants underwent the final examination. Besides these officers, who may all be regarded as being purely voluntary students, there was also a large number of others studying at the college, with a view to passing certain examinations, which would qualify them either for promotion or advancement or for appointment to some special branch or department of the service.

Finally, ten private students are reported as having passed through a course of instruction, nine of the number being foreign officers, a fact which testifies to the estimation in which the college is held abroad.

With regard to the subjects of study we find that, besides the course of mathematics, which is compulsory for all students, systematic courses of instruction, extending over the entire session, are given in physics, chemistry, steam, navigation, and nautical astronomy, marine surveying, permanent and field fortification, military surveying and drawing, military history, foreign languages—namely, French, German, and Spanish—and in freehand drawing. Special courses of lectures are also given on various subjects, among which the principal seem to be the Structural Arrangements of Men-of-War, International Law, Naval History, and Practical Ship-building.

TYPICAL LAWS OF HEREDITY[1]

II.

First let me point out a fact which Quetelet and all writers who have followed in his paths have unaccountably overlooked, and which has an intimate bearing on our work to-night. It is that, although characteristics of plants and animals conform to the law, the reason of their doing so is as yet totally unexplained. The essence of the law is that differences should be wholly due to the collective actions of a host of independent *petty* influences in various combinations, as was represented by the teeth of the harrow, among which the pellets tumbled in various ways. Now the processes of heredity that limit the number of the children of one class such as giants, that diminish their resemblance to their fathers, and kill many of them, are not petty influences, but very important ones. Any selective tendency is ruin to the law of deviation, yet among the processes of heredity there is the large influence of natural selection. The conclusion is of the greatest importance to our problem. It is, that the processes of heredity must work harmoniously with the law of deviation, and be themselves in some sense conformable to it. Each of the processes must show this conformity separately, quite irrespectively of the rest. It is not an admissible hypothesis that any two or more of them, such as reversion and natural selection, should follow laws so exactly inverse to one another that the one should reform what the other had deformed, because characteristics, in which the relative importance of the various processes is very different, are none the less capable of conforming closely to the typical condition.

When the idea first occurred to me, it became evident that the problem might be solved by the aid of a very moderate amount of experiment. The properties of the law of deviation are not numerous and they are very peculiar. All, therefore, that was needed from experiment was suggestion. I did not want proof, because the theoretical exigencies of the problem would afford that. What I wanted was to be started in the right direction.

I will now allude to my experiments. I cast about for some time to find a population possessed of some measurable characteristic that conformed fairly well to the law, and that was suitable for investigation. I determined to take seeds and their weights, and after many preparatory inquiries, fixed upon those of sweet-peas. They were particularly well suited to my purposes; they do not cross-fertilise, which is a very exceptional condition; they are hardy, prolific, of a convenient size to handle, and their weight does not alter when the air is damp or dry. The little pea at the end of the pod, so characteristic of ordinary peas, is absent in sweet peas. I weighed seeds individually, by thousands, and treated them as a census officer would treat a large population. Then I selected with great pains several sets for planting. Each set contained seven little packets, and in each packet were ten seeds, precisely of the same weight. Number one of the packets contained giant seeds, all as nearly as might be of $+3^\circ$ of deviation. Number seven contained very small seeds, all of – 3° of deviation. The intermediate packets corresponded severally to the intermediate degrees ± 2° ± 1° and 0°. As the seeds are too small to exhibit, I have cut out discs of paper in strict proportion to their sizes, and strips in strict proportion to their weights, and have hung below them the foliage produced by one complete set. Many friends and acquaintances each undertook the planting and culture of a complete set, so that I had simultaneous experiments going on in various parts of the United Kingdom. Two proved failures, but the final result was this: that I obtained the more or less complete produce of seven sets, that is of 7 × 7 × 10, or 490 carefully weighed seeds.

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[1] Lecture delivered at the Royal Institution, Friday evening, February 9, by Francis Galton, F.R.S. Continued from p. 495.

It would be wholly out of place if I were to enter into the details of the experiments themselves, the numerous little difficulties and imperfections in them, or how I balanced doubtful cases, how I divided returns into groups, to see if they confirmed one another, or how I conducted any other of the well-known statistical operations. Suffice it to say that I took immense pains, which if I had understood the general conditions of the problem as clearly as I do now, I should not perhaps have cared to bestow. The results were most satisfactory. They gave me two data, which were all that I required in order to understand the simplest form of descent, and so I got at the heart of the problem at once.

Simple descent means this. The parentage must be single, as in the case of the sweet peas which were not cross-fertilised, and the rate of production and the incidence of natural selection must both be independent of the characteristic. The processes concerned in simple descent are those of Family Variability and Reversion. It is well to define these words clearly. By family variability is meant the departure of the children of the same or similarly descended families from the ideal mean type of all of them. Reversion is the tendency of that ideal mean type to depart from the parent type, "reverting" towards what may be roughly and perhaps fairly described as the average ancestral type. If family variability had been the only process in simple descent, the dispersion of the race would indefinitely increase with the number of the generations, but reversion checks this increase, and brings it to a standstill, under conditions which will now be explained.

On weighing and sorting large samples of the produce of each of the seven different classes of the peas, I found in every case the law of deviation to prevail, and in every case the value of 1° of deviation to be the same. I was certainly astonished to find the family variability of the produce of the little seeds to be equal to that of the big ones, but so it was, and I thankfully accept the fact, for if it had been otherwise I cannot imagine, from theoretical considerations, how the problem could be solved.

The next great fact was that Reversion followed the simplest possible law; for the proportion was constant between the deviation of the mean weight of the produce generally and the deviation of the parent seed, reckoning in every case from one standard point. In a typical case, that standard must be the mean of the race, otherwise the deviation would become unsymmetrical, and cease to conform to the law.

I have adjusted an apparatus (Fig. 1) to exhibit the action of these two processes. We may consider them to act not simultaneously but in succession, and it is purely a matter of convenience which of the two we suppose to act the first. I suppose first Reversion then Family Variability. That is to say, I suppose the parent first to revert and then to tend to breed his like. So there are three stages: (1) the population of parents, (2) that of reverted parents, (3) that of their offspring. In arranging the apparatus I have supposed the population to continue uniform in numbers. This is a matter of no theoretical concern, as the whole of this memoir relates to the distinguishing peculiarities of samples irrespectively of the absolute number of individuals in those samples. The apparatus consists of a row of vertical compartments, with trapdoors below them, to hold pellets which serve as representatives of a population of seeds. I will begin with showing how it expresses Reversion. In the upper stage of the apparatus the number of pellets in each compartment represents the relative number in a *population* of seeds, whose weight deviates from the average, within the limits expressed by the distances of the sides of that compartment from the middle point. The correct shape of the heap has been ensured by my having cut a slit of the proper curvature in the board that forms the back of the apparatus. As it is glazed in front I have only to pour pellets in from above until they reach the level of the slit. Such overplus as may have been poured in will run through the slit, to waste, at the back. The pellets to the right of the heap represent the heaviest seeds, those to the left the lightest. I shall shortly open the trap-door on which the few representatives of the giant seeds rest. They will run downwards through an inclined shoot, and fall into another compartment nearer the centre than before. I shall repeat the process on a second compartment in the upper stage, and successively on all the others. Every shoot converges towards one standard point in the middle vertical line; thus the present shape of the heap of pellets is more contracted in width than it was before, and is of course more humped up in the middle. We need not regard the humping up; what we have to observe is that each degree of deviation is simultaneously lessened. The effect is as though the curve of the first heap had been copied on a stretched sheet of india-rubber that was subsequently released. It is obvious from this that the process of reversion cooperates with the general law of deviation. Fig. 6 shows the principle of the process of reversion clearly.

I have now to exhibit the effects of variability among members of the same family. It will be recollected that the produce of peas of the same class deviated normally on either side of their own mean weight; that is to say, I must make the pellets which were in each of the upper compartments to deviate on either side of the compartment in which they now lie, which corresponds to that of the medium weight of their produce. I open the trap-door below one of the compartments in the second stage, the pellets run downwards through the harrow, dispersing as they run, and form a little heap in the lowest compartments, the centre of which heap lies vertically below the trap-door through which they fell. This is the contribution to the succeeding generation of all the individuals belonging to the compartment in the upper stage from which they came. They first reverted and then dispersed. I open another trap-door, and a similar process is gone through; a few extreme pellets in this case add themselves to the first formed heap. Again, I continue the process; heap adds itself to heap, and when all the pellets have fallen through, we see that the aggregate contributions bear an exact resemblance to the heap from which we originally started. A simple formula (see Appendix) expresses the conditions of equilibrium. I attended to these, when I cut out the slit in the back board of the upper compartment, by which the shape of the original heap was regulated. Thus it follows from the formula that if deviation after reversion was to deviation before reversion as 4 to 5, and if 1° of family variability was six units, then the value of 1° in the population must be ten units.

It is easy to prove that the bottom heap is strictly a curve of deviation, and that its scale tends invariably to become the same as that of the upper one. It will be recollected that I showed that every variety of curve of deviation was producible by variations in the length of the harrow, and that if the pellets were intercepted at successive stages of their descent they would form a succession of curves of increasing scales of deviation. The curve in the second stage may therefore be looked upon as one of these intercepts; all that it receives in sinking to the third stage being an additional dose of dispersion.

As regards the precise scale of deviation that characterises each population, let us trace, in imagination, the history of the descendants of a single medium-sized seed. In the first generation the differences are merely those due to family variability; in the second generation the tendency to wider dispersion is somewhat restrained by the effect of reversion; in the third, the dispersion again increases, but is more largely restrained, and the same process continues in successive generations, until the step-by-step progress of dispersion has been overtaken and exactly checked by the growing antagonism of reversion. Reversion acts precisely after the law of an elastic spring, as was well shown by the illustration of the india-rubber sheet. Its tendency to recoil increases the more it is stretched, hence equilibrium must at length ensue between reversion and family variability, and therefore the scale of deviation of the lower heap must after many generations always become identical with that of the upper one.

We have now surmounted the greatest difficulty of our problem; what remains will be shortly disposed of. This refers to sexual selection, productiveness, and natural selection. Let us henceforth suppose the heights and every other characteristic of all members of a population to be reduced to a uniform adult male standard, so that we may treat it as a single group. Suppose, for example, a female whose height was equal to the average female height + 3° of female deviation, the equivalent in terms of male stature is the average male height + 3° of male deviation. Hence the female in question must be registered not in the feet and inches of her actual height, but in those of the equivalent male stature.

On this supposition we may take the numerical mean of the stature of each couple as the equivalent of a single parent, so that a male parent plant having 1° deviation and a female parent plant having 2° of deviation, would together rank as a single fertilised plant 0 + $1\frac{1}{2}$°.

In order that the law of sexual selection should co-operate with the conditions of a typical population, it is necessary that selection should be *nil*, that is, that there should not be the least tendency for tall men to marry tall women rather than short ones. Each strictly typical quality taken by itself must go for nothing in sexual selection. Under these circumstances one of the best known properties of the law of deviation (technically called that of "two fallible measures") shows that the population of sums of couples would conform truly to the law, and the value of 1° would be that of the original population multiplied by $\sqrt{2}$. Consequently the population of *means of couples* would equally conform to the law, but in this case the 1° of original deviation would have to be divided by $\sqrt{2}$, the deviations of means of couples being half that of sums of couples.

The two remaining processes are productiveness and survival. Physiologically they are alike, and it is reasonable to expect the same general law to govern both. Natural selection is measured by the percentage of survival among individuals born with like characteristics. Productiveness is measured by the average number of children from all parents who have like characteristics, but it may physiologically be looked upon as the percentage of survival of a vast and unknown number of possible embryos, producible by such parents. The number being unknown creates no difficulty if they may be considered to be, on the average, the same in every class. Experiment could tell me little about either natural selection or productiveness. What I have to say is based on plain theory. I can explain this best by the process of natural selection. In each species, the height, &c., the most favoured by natural selection, is the one in which the demerits of excess or deficiency are most frequently balanced. It is therefore not unreasonable to look at nature as a marksman, her aim being subject to the same law of deviation as that which causes the shot on a target to be dispersed on either side of the point aimed at. It would not be difficult, but it would be tedious, to justify the analogy; however, it is unnecessary to do so, as I propose to base the analogy on the exigences of the typical formula, no other supposition being capable of fulfilling its requirements. Suppose for a moment that nature aims, as a marksman, at the medium class, on purpose to destroy and not to save it. Let a block of stone (Fig. 4) represent a rampart, and let a gun be directed at a vertical line on its side on purpose to breach it: the shots would fall with the greatest frequency in the neighbourhood of the vertical line, and their marks would diminish in frequency as the distance increased, in conformity with the law of deviation. Each shot batters away a bit of stone, and the shape of the breach would be such that its horizontal outline will be the well-known curve. This would be the action of nature were she to aim at the destruction of medium sizes. Her action as preserver of them is the exact converse, and would be represented by a cast that filled the gap and exactly replaced the material that had been battered away. The percentage of thickness of wall that had been destroyed at each degree of deviation is represented by the ordinate of the curve, therefore the percentage of survival is also an ordinate of the same curve of deviation. Its scale has a special value in each instance, subject to the general condition in every typical case, that its 0° shall correspond to the 0° of deviation of height, or whatever the characteristic may be.

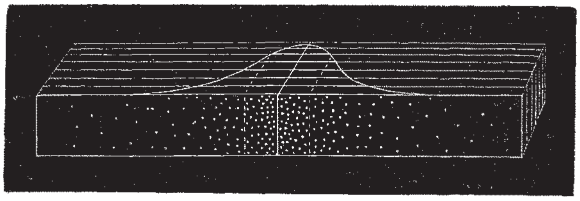

FIG. 4.

In Fig. 5 the thickness of wall that has been destroyed at each degree of deviation is represented by the corresponding ordinate of the horizontal outline of the portion which remains. Similarly, in the case of an original population, in which each class was equally numerous, the amount of survivors at each degree of deviation is also represented by the corresponding ordinate of this or a similar curve.

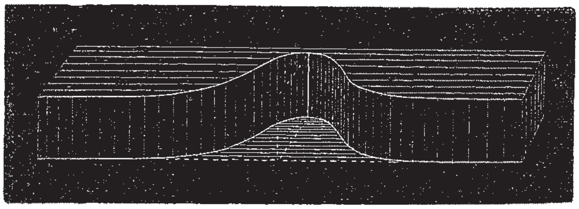

FIG. 5.

But in the original population at which we are supposing nature to aim the representatives of each class are not equally numerous, but are arranged according to the law of deviation; the middle class being most numerous, while the extreme classes are but scantily represented. The ordinate of the above-mentioned outline will in this case represent, not the *absolute number*, but the *percentage* of survivors at each degree of deviation.

(*To be continued.*)